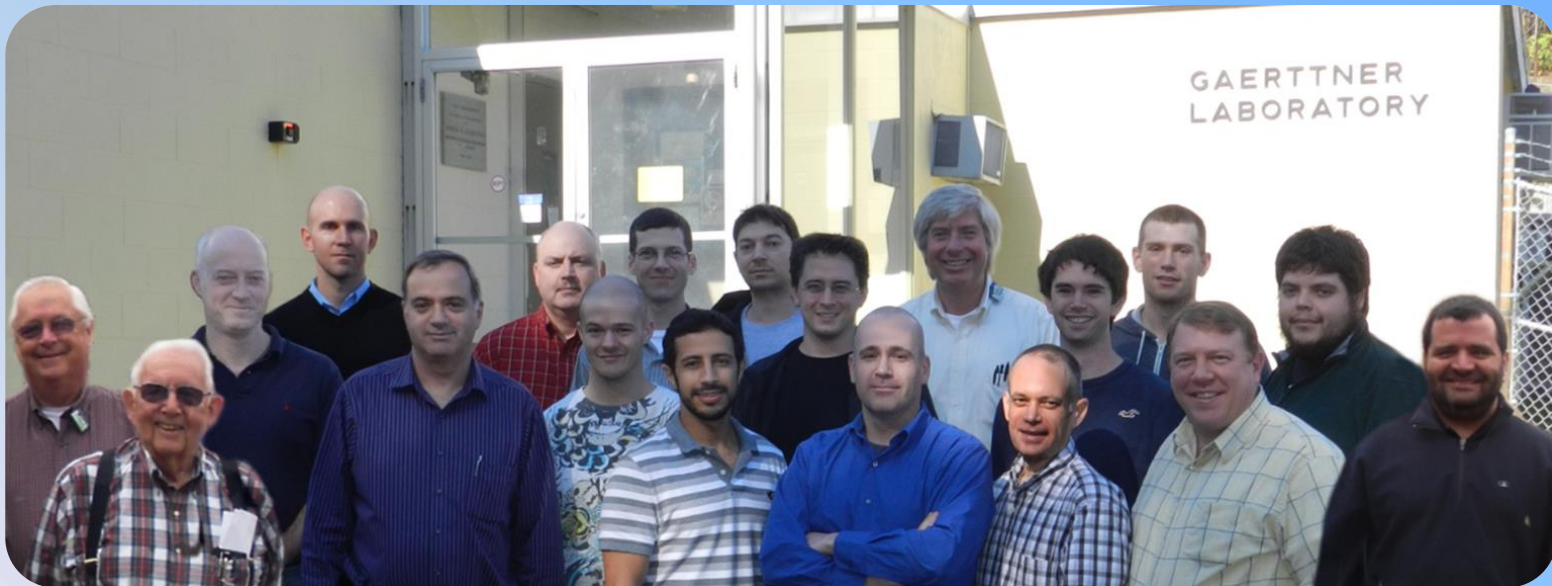


Nuclear Data Measurements at the Gaerttner LINAC Center at RPI

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NCSP Meeting Washington DC May 30 2013

FY 2011-2013 (Technical) Milestones Overview

FY 2011

1. **Analysis:** Complete SAMMY analysis on Gd (Q1).
2. **Capability development:** Complete calculations to estimate efficiencies for several detector concepts (C_6D_6 , BaF_2 , NE-226) (Q2).
3. **Capability development:** Purchase prototype detectors of the selected concepts and perform scoping measurements with prototype detectors (Q4).
4. **Measurements:** Measure ^{56}Fe total cross section in the high energy range (0.5 MeV-20 MeV) (Q3).

FY 2012

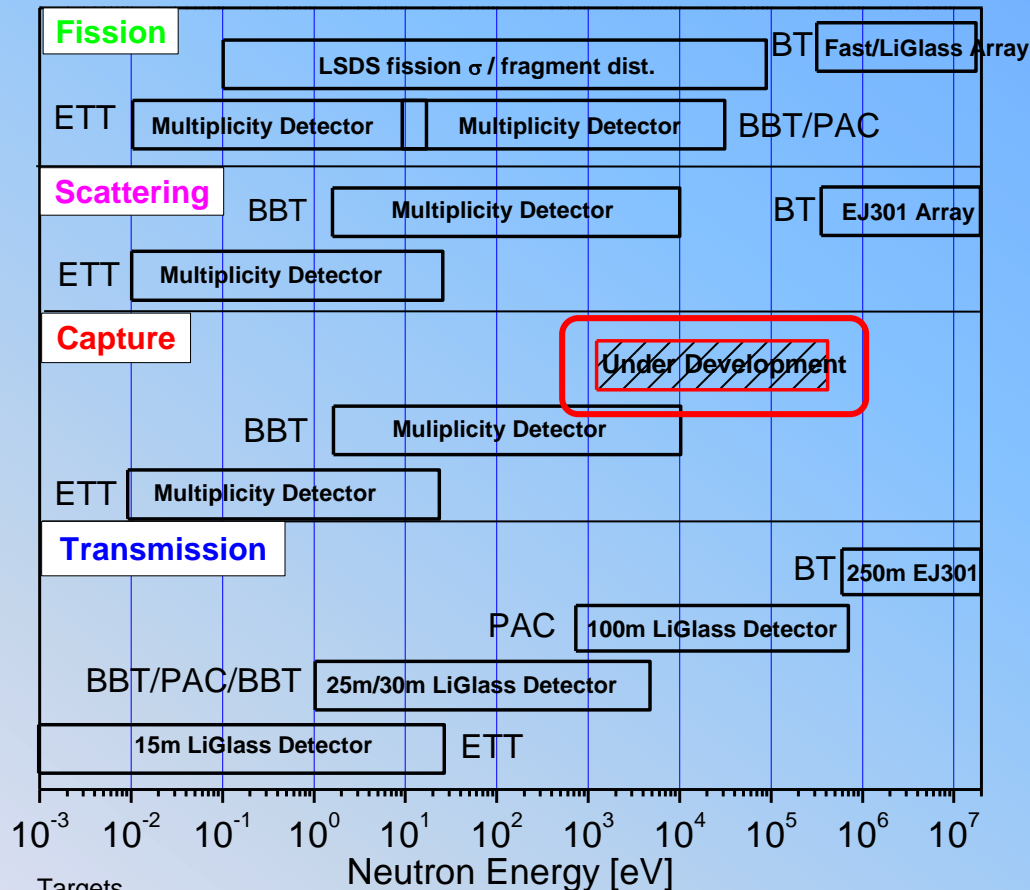
1. **Documentation:** Complete ^{56}Fe documentation (carry over from FY11) (Q1)
2. **Capability development:** Perform scoping measurements with prototype detectors (Q2)
3. **Measurements:** Complete measurement of ^{238}U scattered and fission neutrons (0.5-20 MeV) (Q4).
Measurements: Complete transmission measurements to supplement ORNL measurements planned at Institute for Reference Materials and Measurements (Q4).

FY 2013

1. **Capability development:** Complete construction of RPI capture detection system and qualify system.
2. **Measurements:** Perform thermal neutron scattering measurements of water at elevated temperatures from room temperature up to 550K and SiO_2 (glass) at room temperature (as an example of other moderators) (Q4) (**currently SNS is down, LANSCE instrument is not operational, exploring other options**)

Capability Development

- Develop Mid energy (1 - 300 keV) capture detector



Targets

ETT- Enhanced Thermal Target

BBT - Bare Bounce Target

BT- Bare Target on Axis

PAC - PacMan Target

New Flight Station

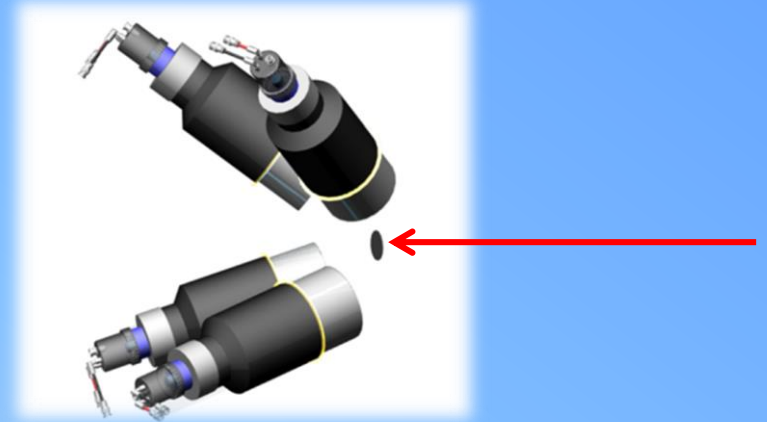


- Flight Station construction completed in FY 12
- **FY 13 plan**
 - ✓ Install capture detector array
 - Install evacuated flight tubes
 - Design a sample changer



Mid-Energy Capture Detector

- 4 deuterated benzene (C_6D_6) liquid scintillators with low neutron sensitivity
- Located at newly constructed 40m flight station
- 10-bit, 8 channel Struck Systems SIS3305 digital data acquisition system allows for low dead time operation
- Low mass design to minimize background contributions from neutrons captured in detector and surrounding structural materials



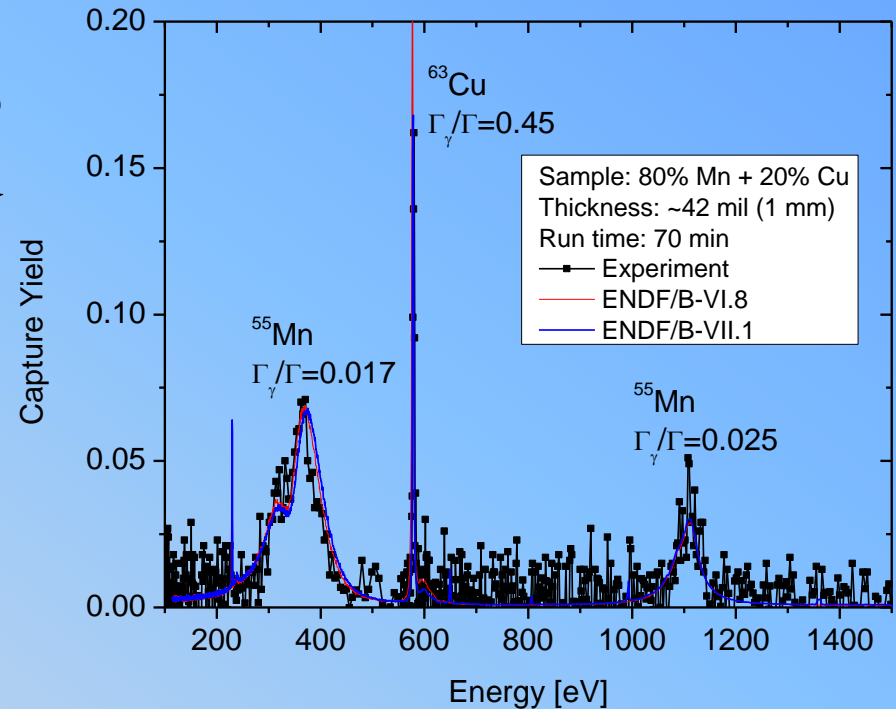
CAD model of the detector array and sample



A picture of the prototype detector

Mid-Energy Capture Detector First Test

- Capture measurements performed on Mn/Cu sample using existing analog TOF setup
- Experimental results are in good agreement with ENDF/B-VI.8 and VII.1 data libraries
- No contribution from scattered neutrons is apparent
- Future experiments will incorporate a digital DAQ system



Detector Array Installed at the 45 flight station

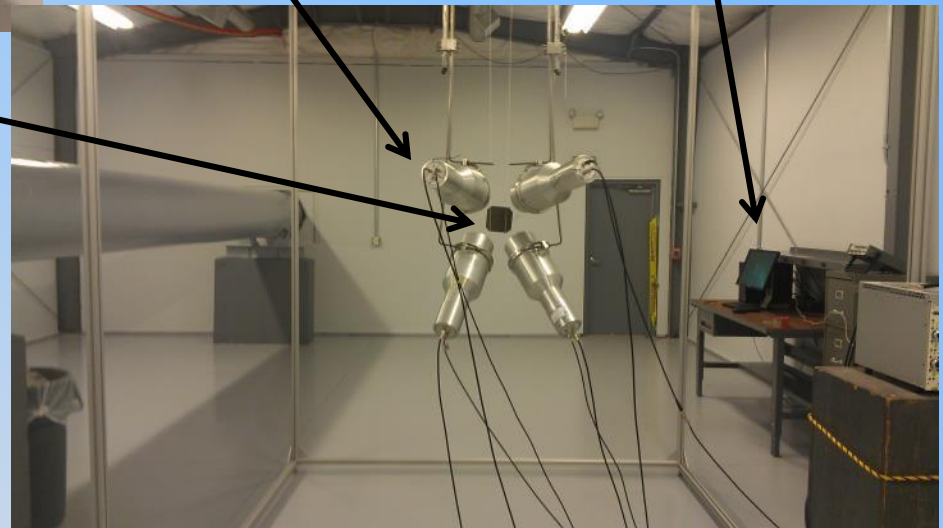
- Detector array is mounted in low mass structure to reduce neutron sensitivity
- DAQ test was performed
- Software is under development

C_6D_6 Detectors DAQ Computer

Test
Sample

Struck SIS3305

8 channel 10 bit 5 GS/s Digitizer



Measurements Completed in FY 12

- **Transmission**

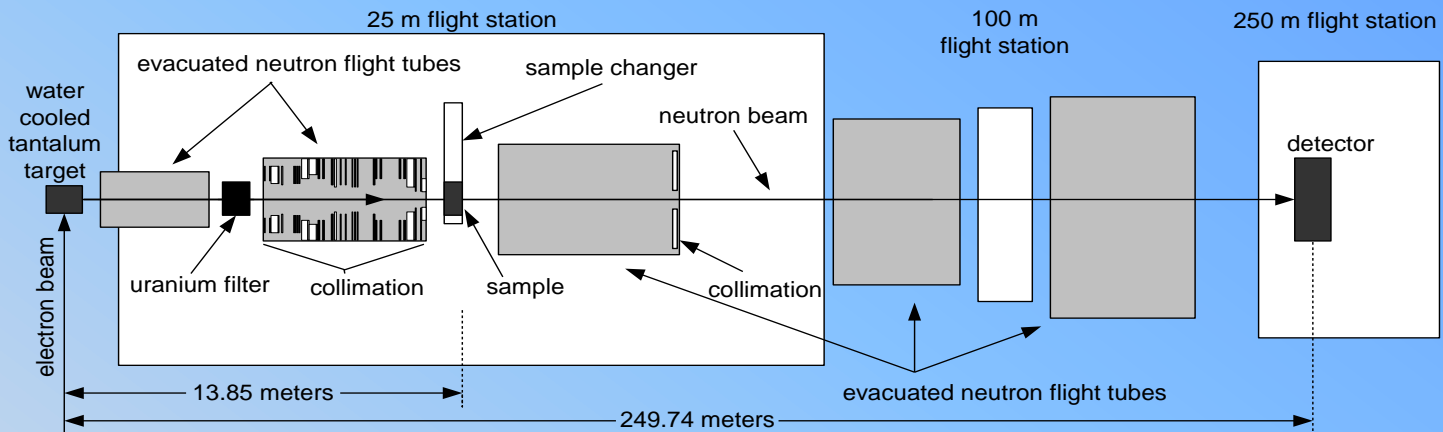
- ^{56}Fe , 0.5-20 MeV, 250m flight path
- Cu, 0.5-20 MeV, 250m flight path



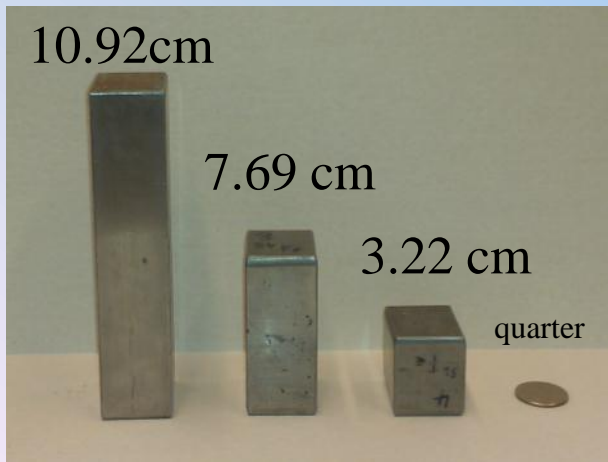
- **Scattering (analysis)**

- ^{238}U , Neutron Scattering (7 angles), 0.5-20 MeV, 30m flight path.
- ^{56}Fe , Neutron Scattering (7 angles), 0.5-20 MeV, 30m flight path

250m Transmission Experimental Setup

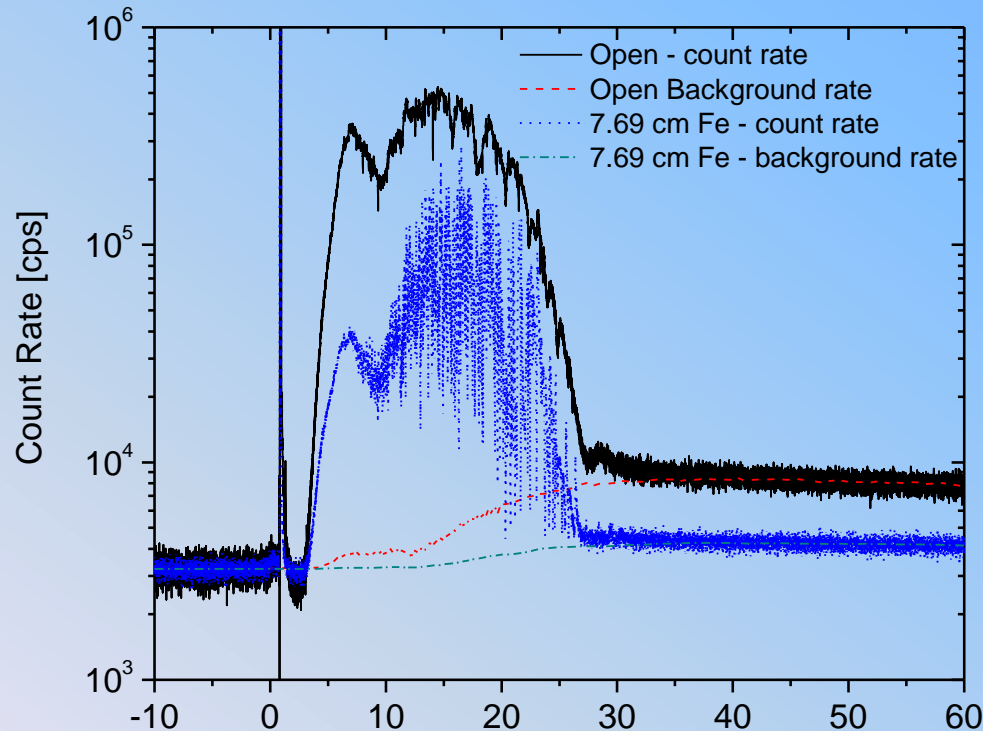


Fe-56 Samples



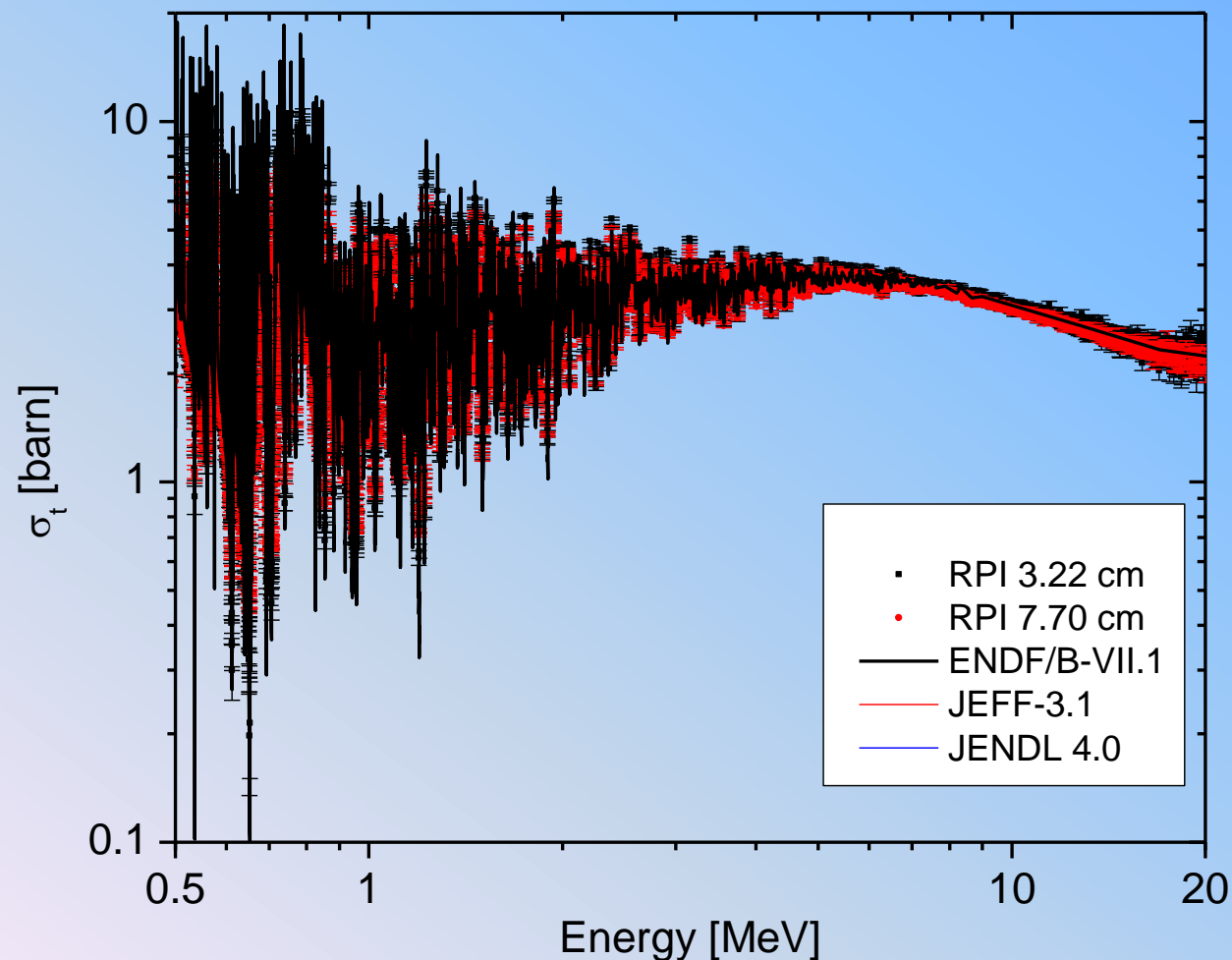
250m Time of Flight and Background Spectra

- Background is mostly from gamma interaction with the detectors
 - Used 1" diam. beam
 - Shape calculated using MCNP and fitted to measured data
 - Verified using thick carbon samples.



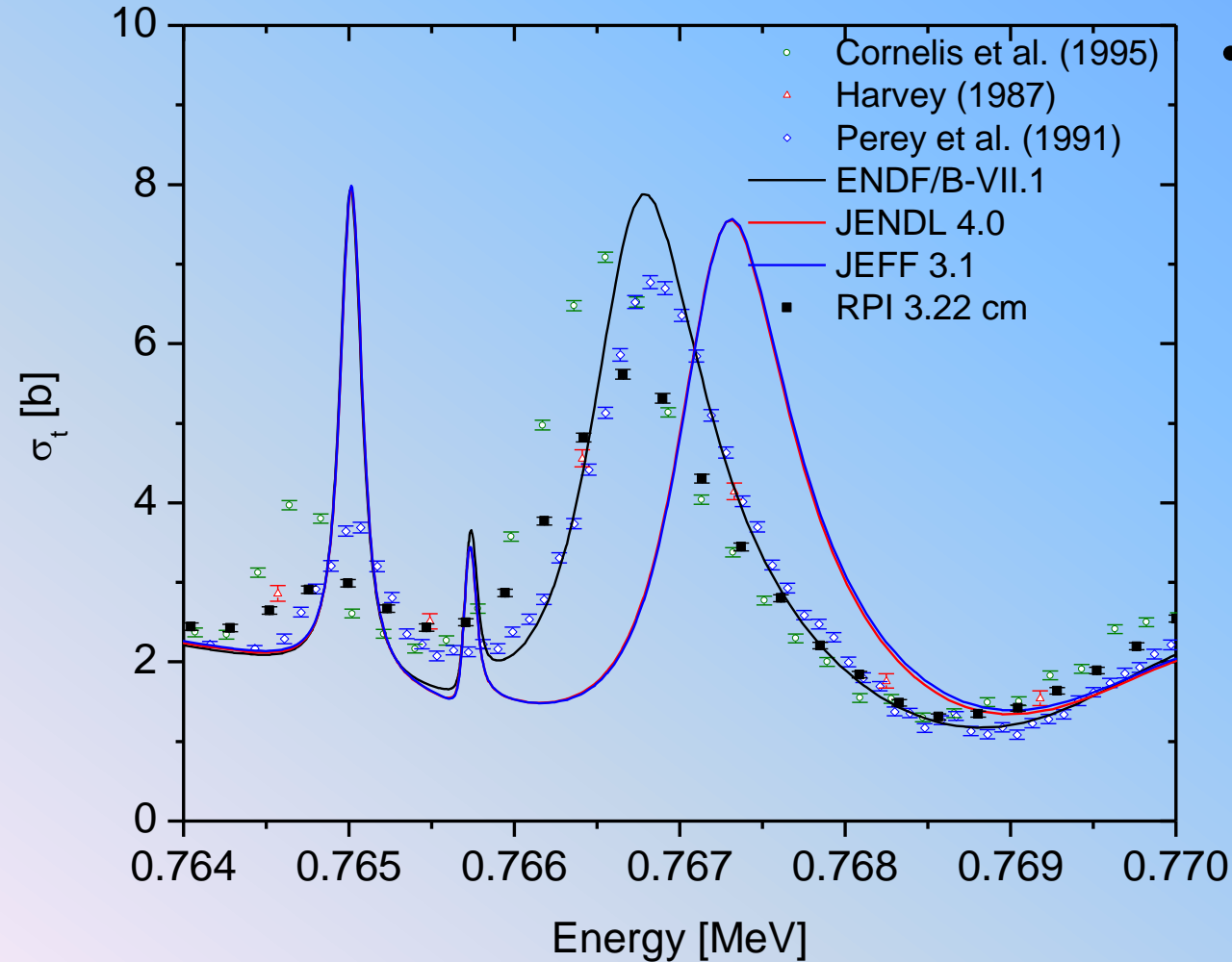
^{56}Fe Total Cross Section Measurements (NCSP)

250 m Flight Path



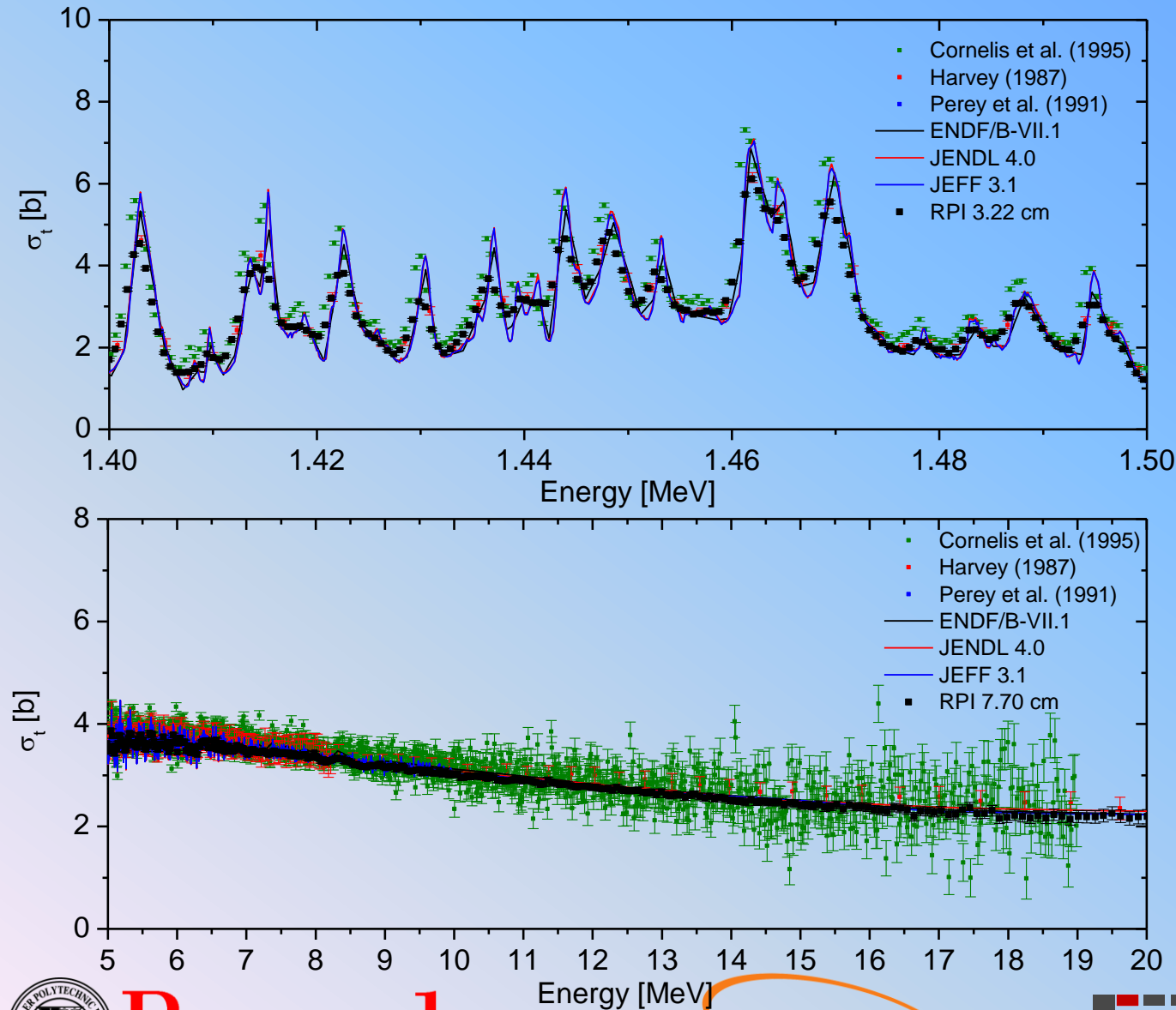
- Measured at 250 m flight station with 8 ns pulse width.
- Three sample thicknesses were used 3.22 cm, 7.7 cm, and 10.9 cm
- Sample is 99.87% metallic ^{56}Fe
- Can help extend the resolved resonance region above 892 keV
- Above 900 keV only two other data sets are available on EXFOR (Harvey et al. and Cornelis et al.)

Fe-56 Total Cross Section – $E < 1$ MeV



- There is an energy shift between the experiment and evaluations

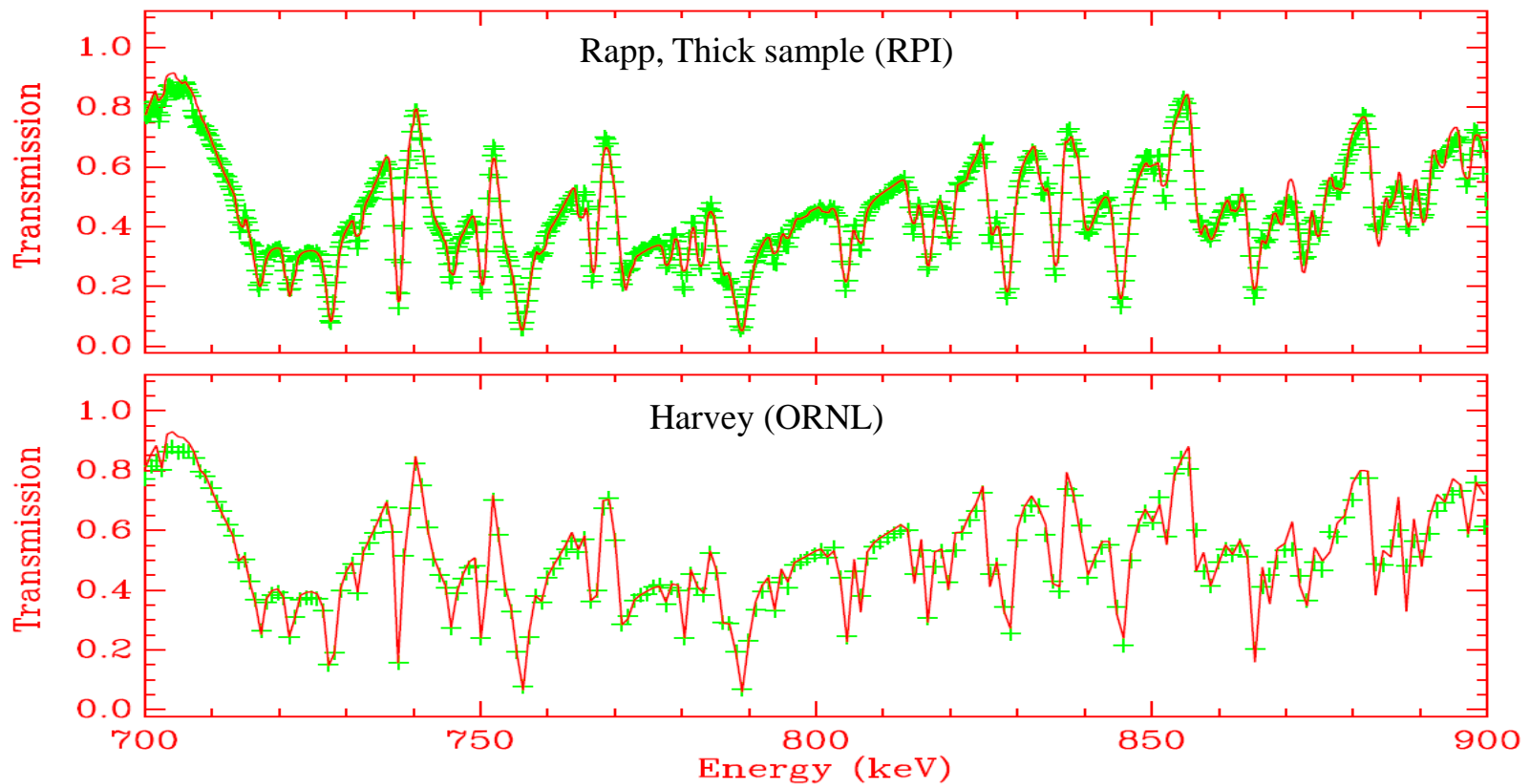
^{56}Fe Total Cross Section Measurements



- New data have good energy resolution but lower than Cornelis et al.
- The Cornelis et al. data are based on an oxide sample Fe_2O_3 (corrected for O_3)
- Above 10 MeV the data have low errors and are in good agreement with both ENDF/B-VII.1 and JEFF 3.1

Fe-56 SAMMY Fit From ORNL

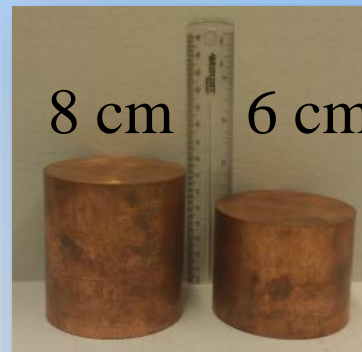
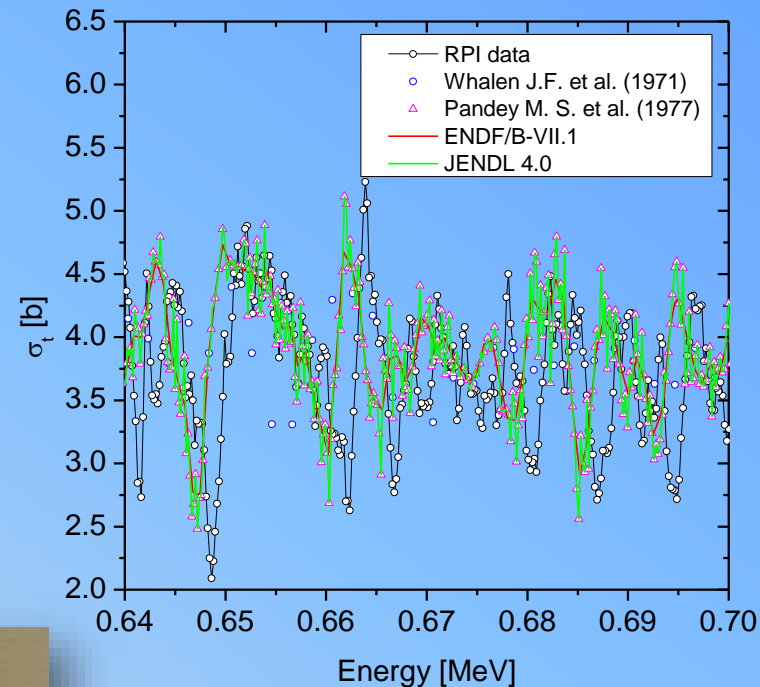
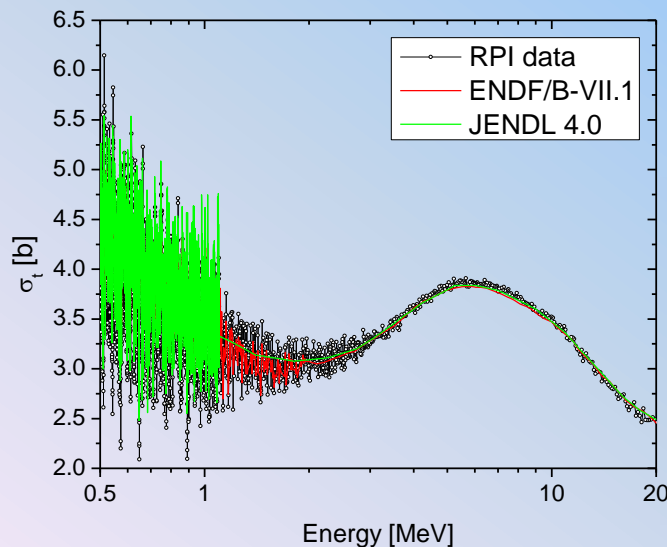
- The RPI transmission data are in good agreement with the Harvey data with slightly better energy resolution



Cu Total Cross Section Measurements

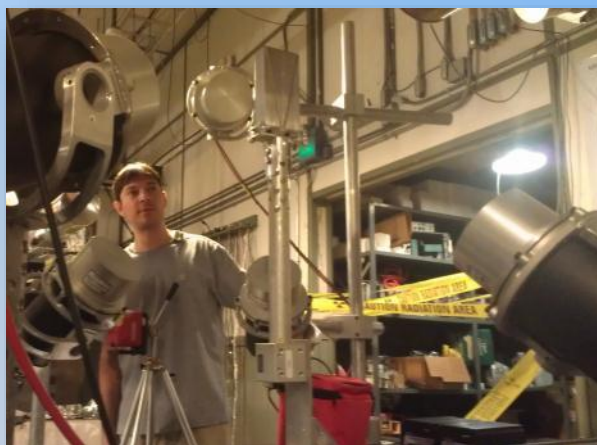
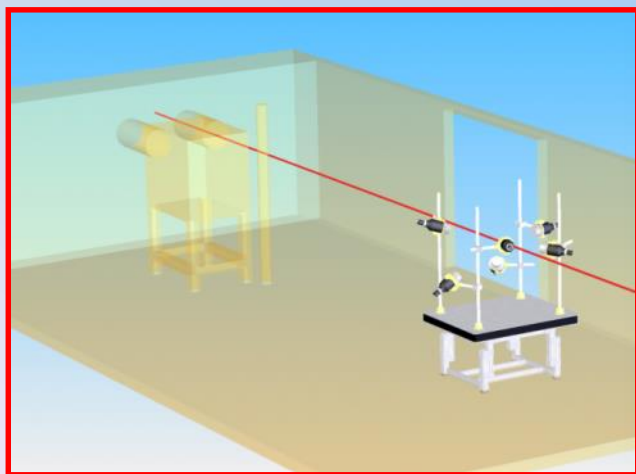
0.5 – 20 MeV (250m flight path)

- All Evaluations similar with the exception of JENDL 4.0
 - Follows the isotopic measurements by Pandey et al.
 - JENDL shows more structure below 1.1 MeV, but smoothes to average value prior to other libraries (1.1 MeV vs. 2.0 MeV)
- Shift in energy seen in evaluations



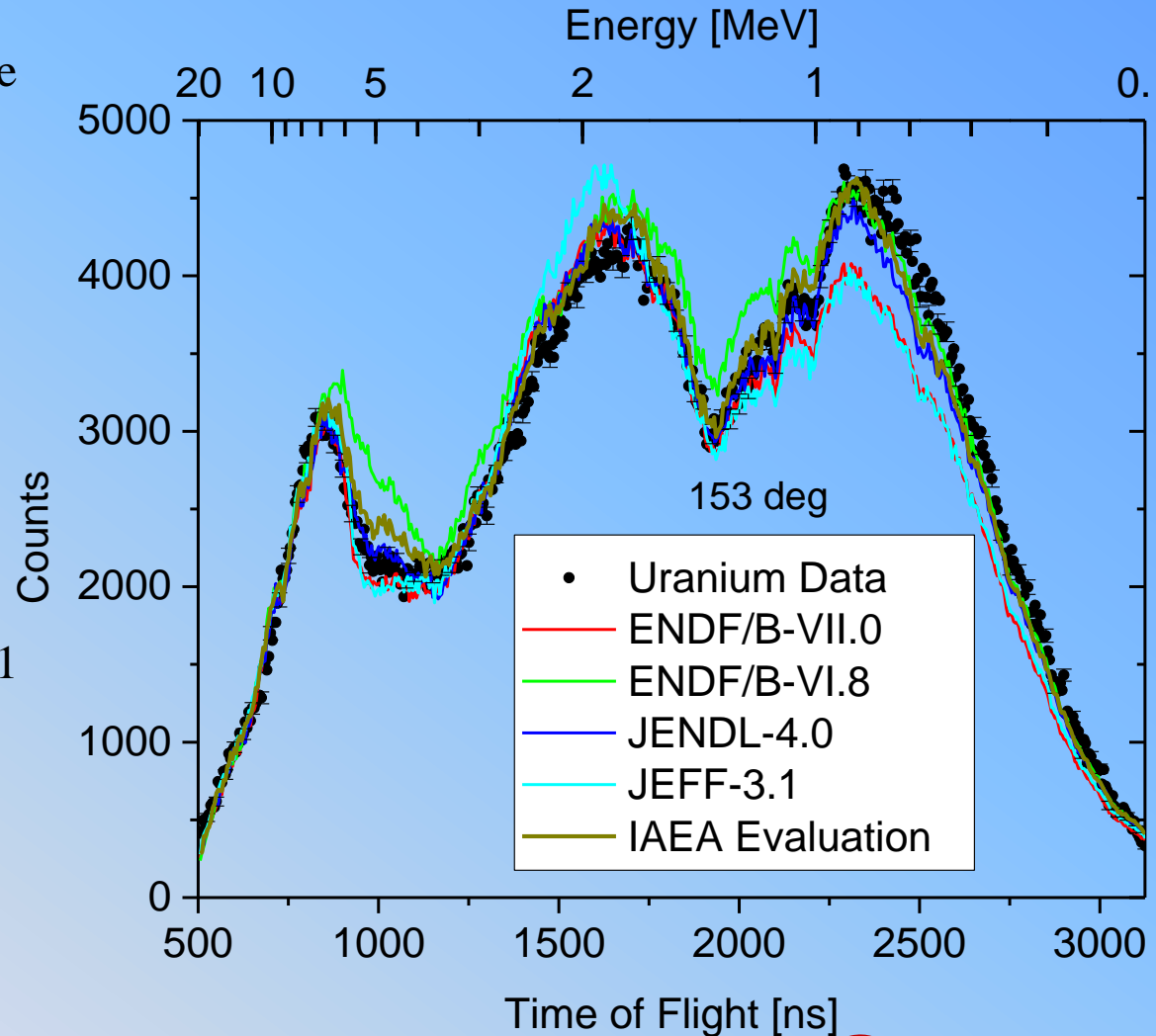
^{238}U Scattering/Fission Measurement

- Measured in September 2011.
- Measured scattered (elastic+ inelastic) and fission neutrons
- Use ^{238}U sample thickness of 0.375" (0.95 cm)
- Measured at angles of 27, 77, 112, 156 (two detectors at each angle)
- Compared measured data to MCNP simulations
 - Obtain neutron flux shape from a U-235 fission chamber in beam
 - Obtain detector efficiency curves from an in beam measurement with EJ-301 detectors
- Use 7 cm graphite sample for verification of system and methodology



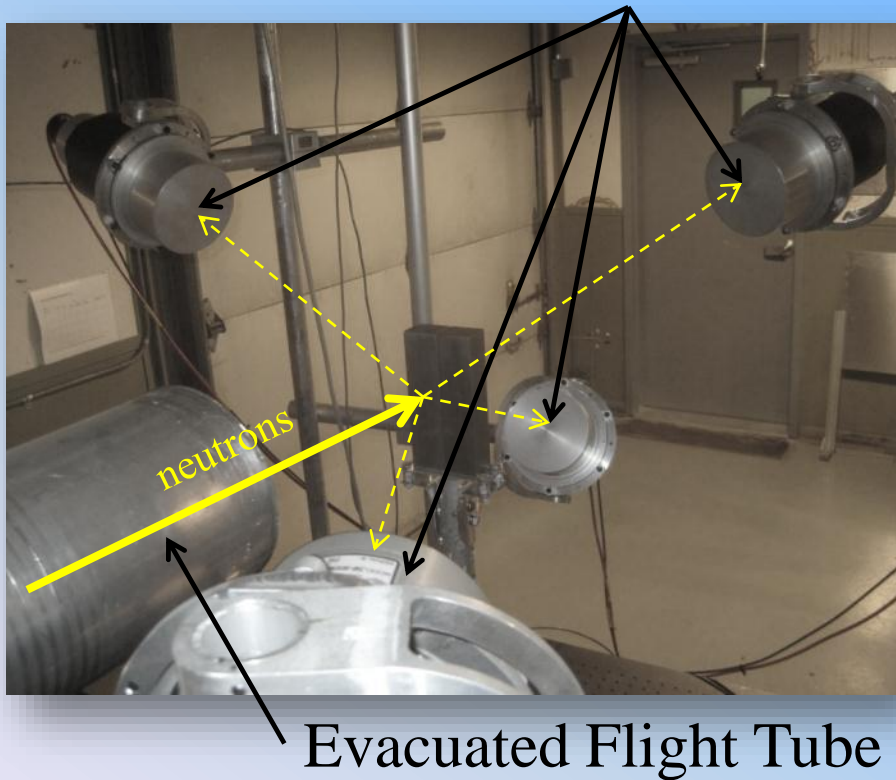
^{238}U Scattering Revisited

- Following the WINS meeting we interacted with Andrej Trkov and Roberto Capote from IAEA to help improve new ^{238}U evaluation
- The new evaluation performed well at forward angles
- At back angles the IAEA evaluations with JEFF angular distributions performed better than JEFF3.1 and ENDF/B-VII.1
- At this angle the new evaluation has similar χ^2 as JENDL 4.0



^{56}Fe Scattering Measurement - Setup

EJ-301 Liquid Scintillator Neutron Detectors



- ^{56}Fe Sample
- 99.87% metallic ^{56}Fe
- Dimensions 77.0 x 152.6 x 32.2 mm

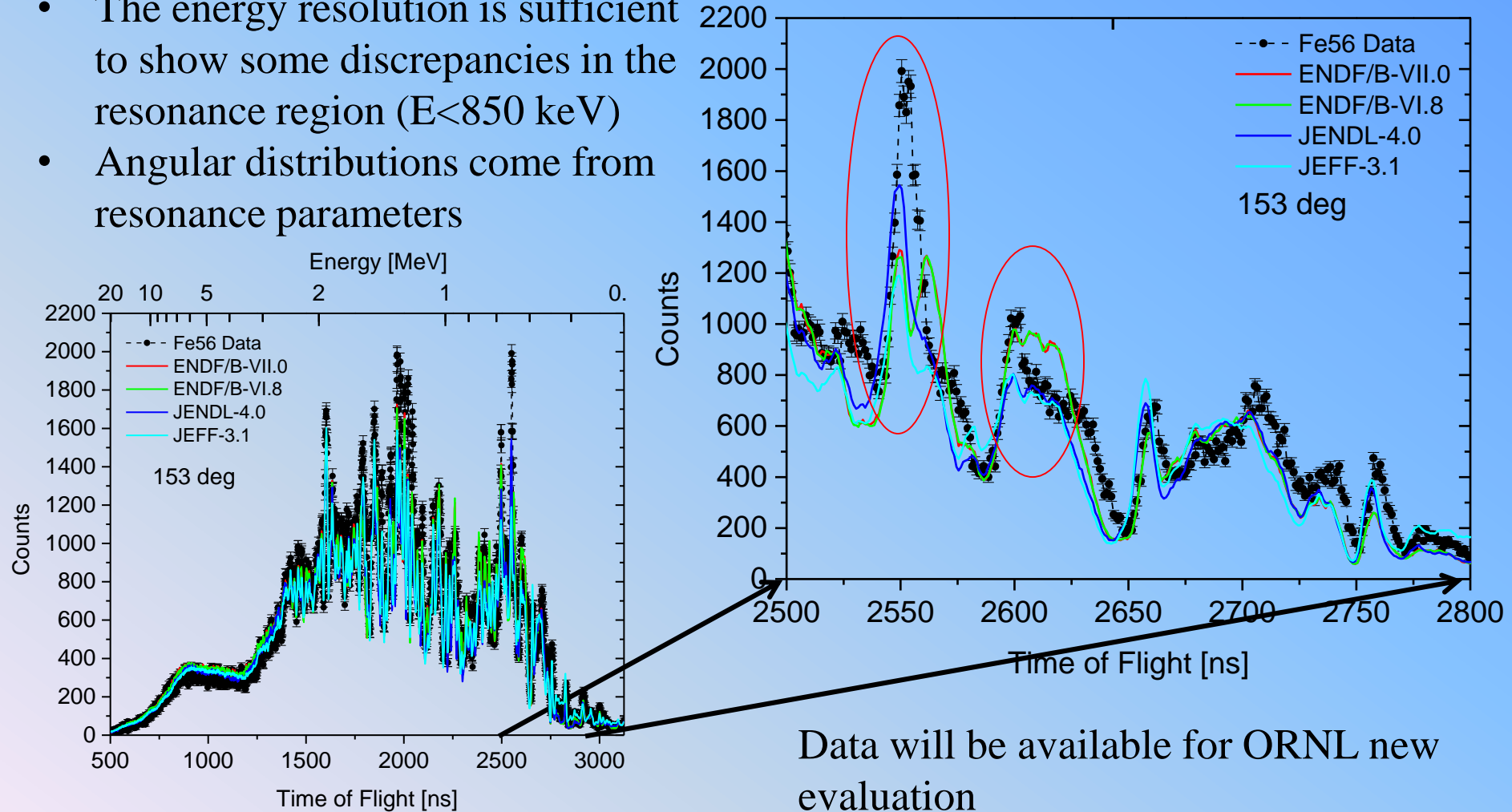


The neutron beam size is smaller than the sample.

^{56}Fe Scattering Measurement – Results 153°

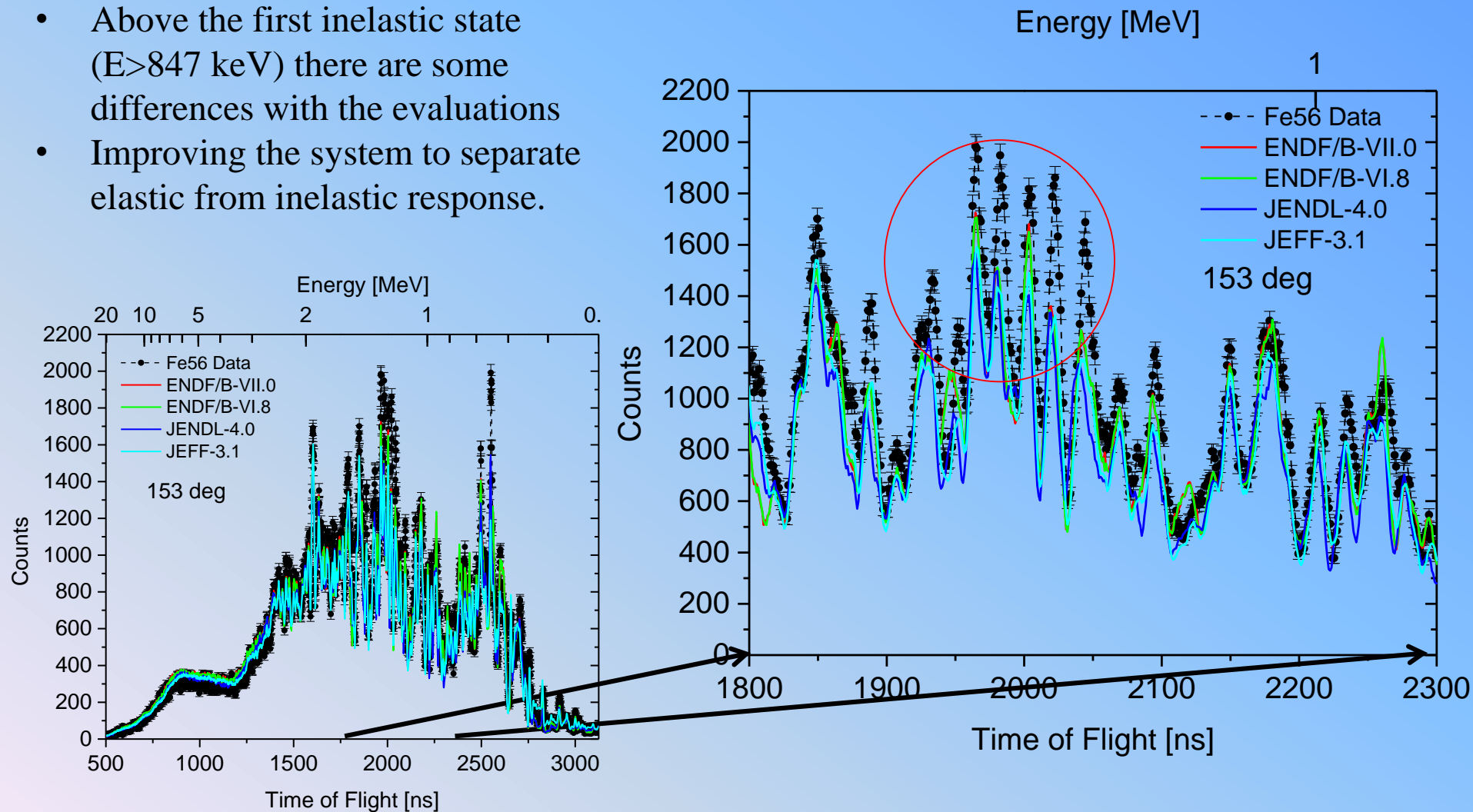
Energy [MeV]

- The energy resolution is sufficient to show some discrepancies in the resonance region ($E < 850$ keV)
- Angular distributions come from resonance parameters



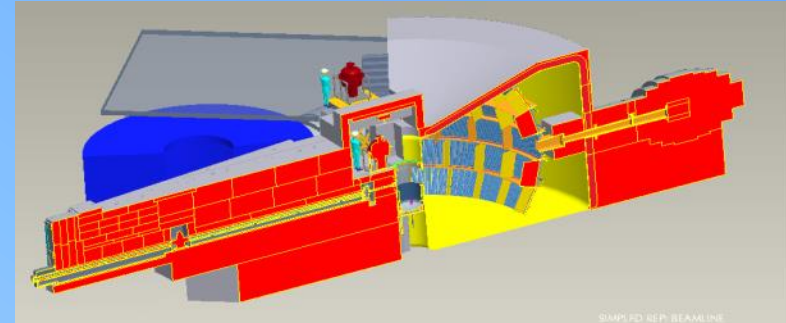
Fe-56 Scattering Measurement – Results 153°

- Above the first inelastic state ($E > 847$ keV) there are some differences with the evaluations
- Improving the system to separate elastic from inelastic response.



Thermal Scattering Experiment at SEQUOIA (SNS)

- SEQUOIA:
 - Fine-Resolution Fermi Chopper Spectrometer at SNS
 - $E_i = 10$ to 2000 meV
 - 900 ^3He detector tubes
 - Scattering angles: -30° to -3° horizontal and 3° to 60° vertical
 - Flux: $> 1 \times 10^5$ neutrons/cm 2 /s
 - Resolution: $\Delta E/E_i \sim 1\%$



- Double differential cross section for inelastic scattering at temperature T:

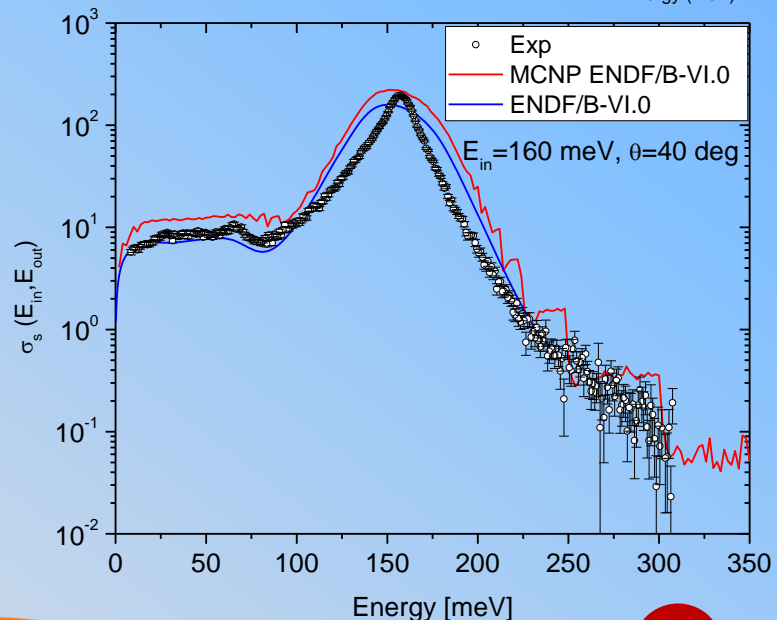
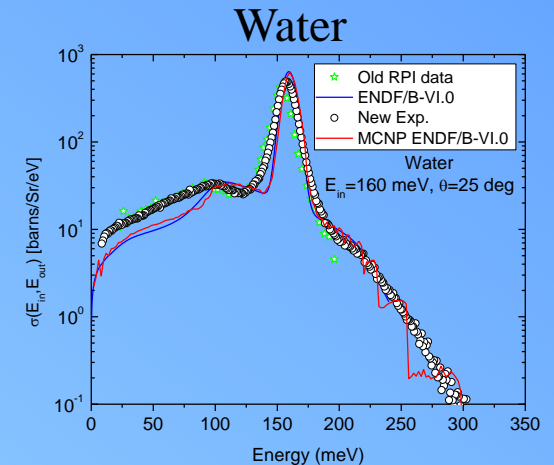
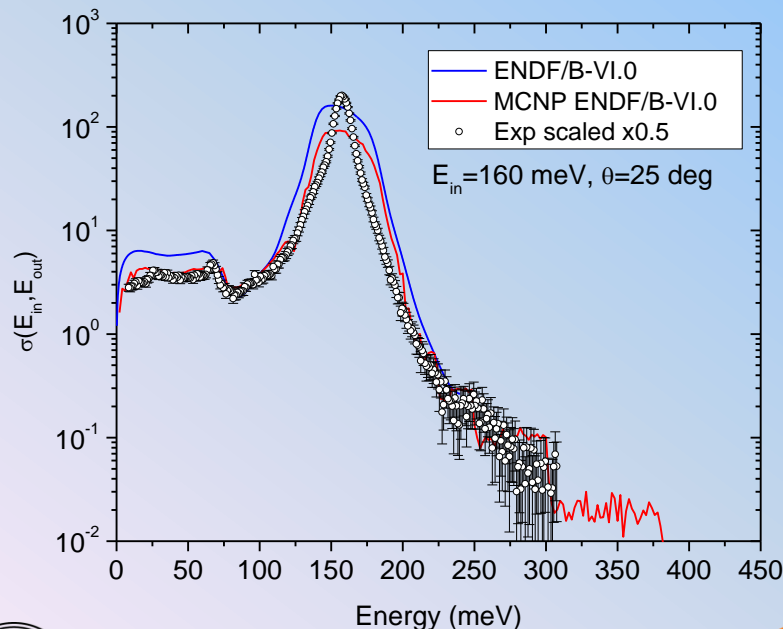
$$\frac{d^2\sigma}{d\Omega dE'}(E \rightarrow E', \Omega \rightarrow \Omega') = \frac{\sigma_b}{4\pi kT} \sqrt{\frac{E'}{E}} e^{-\frac{\beta}{2}} S(\alpha, \beta, T)$$

$$\alpha = \frac{E' + E - 2\sqrt{E'E \cos \theta}}{AkT} = \frac{\hbar^2 \kappa^2}{2MkT}$$

$$\beta = \frac{E' - E}{kT} = \frac{\varepsilon}{kT}$$

New Data for Medium Density Polyethylene

- Data measured at SNS
- Sample thickness 0.15 mm
- Arbitrary normalization – needs to be resolved
- Poly experimental data show a sharper energy transfer peak



Status to date

- Personnel
 - Two graduate students joined this project.
- Experiments and Analysis
 - Students and Prof. Liu visited ORNL and SNS
 - Met with Luiz Leal
 - Established access to SNS computer for analysis of previous RPI measurements of H_2O and CH_2
- Beam time
 - Due to problems with SNS our request for beam time was not approved
 - Working with Mike Dunn to get SNS beam time through the SNS management
 - LANSCE instrument is not functional
 - Backup plan - measurement at JPARC (Japan) ISIS (England)

Summary

- NCSP program at RPI is focused on Nuclear Data measurements:
 - The program is a collaboration with KAPL/RPI and NCSP
 - Leverages all the equipment and experience available to the KAPL/RPI group
 - Contributes to the establishment of new experimental capabilities
 - Educates undergraduate, graduate, and postdoctoral students in experimental neutron physics and experimental techniques
- Results to date
 - Finished capture measurements, data reduction, and SAMMY analysis of Gd isotopes
 - Data for Gd and Dy were delivered to ORNL
 - Publication of Gd data is in preparation
 - Measured total cross section of ^{56}Fe from 0.5 to 20 MeV
 - Data were delivered to ORNL
 - Completed scattering/fission measurements and analysis for ^{238}U
 - Completed scattering measurements for ^{56}Fe
 - Developing a new capability to measure capture cross sections in the mid energy (keV) range
 - Detector array was installed
 - Software is under development, front end is under tests.
 - Flight path pipes were ordered (vacuum pump received).
 - Sample changer order is in preparation